Review article

Lipids in monogastric animal meat

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Abstract — Meat from monogastric animals, essentially pigs and poultry, is from afar the most consumed of all meats. Meat products from every species have their own characteristics. For a long time, pig meat has been presented as a fatty meat because of the importance of subcutaneous adipose tissue. Actually, when the visible fat is separated, this meat is rather poor in lipids: pieces eaten as fresh meat and without transformation, such as roasts, contain less then 2% total lipids. Poultry meat has always had a reputation of leanness because of its low content in intramuscular lipids. In addition, adipose tissues, localised in the abdominal cavity, are easily separable. The progress in genetics and a better knowledge of dietary needs has allowed to improve growth performances, to increase muscle weight and, in the pig, to strongly decrease carcass adiposity. However, strong contradictions appear between transformers and nutritionists, especially concerning the pig: the former wish to have meat with adipose tissues containing a high percentage of saturated fatty acids and the latter wish meat with more unsaturated fatty acids. The consumer, however, regrets the pigs of yesteryear or the poultry bred on farmyard that had tastier meat. At the same time, however, they request meat with a low fat content, which is paradoxical.

meat / pig / poultry / lipid / fatty acid

Résumé — **Les lipides dans la viande des animaux monogastriques.** La viande des animaux monogastriques terrestres, essentiellement les porcs et les volailles, est, de loin, la plus consommée. Les produits carnés de chaque espèce ont chacun leurs caractéristiques. La viande de porc a longtemps été présentée comme une viande grasse en raison de l'importance de la masse adipeuse de couverture. En réalité, quand le gras visible est écarté, cette viande apparaît assez pauvre en lipides car les morceaux consommés en frais et sans transformation, comme les rôtis, contiennent moins de 2 % de lipides totaux. Celle de volaille a toujours eu une réputation de viande maigre en raison de sa faible teneur en lipides intramusculaires, tandis que les dépôts adipeux, bien localisés au niveau de la cavité abdominale, sont facilement séparables. La sélection génétique, la meilleure connaissance des besoins alimentaires et des matières premières ont permis d'améliorer les performances d'élevage, d'augmenter les masses musculaires et chez le porc de diminuer fortement l'adiposité globale de la carcasse. De fortes contradictions apparaissent cependant entre les transformateurs, surtout dans le cas du porc, qui

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souhaitent disposer d'une viande avec des tissus adipeux contenant un fort pourcentage d'acides gras saturés et les nutritionnistes qui souhaitent une viande contenant davantage d'acides gras insaturés. Tout aussi paradoxalement, le consommateur, quant à lui, regrette les porcs d'antan ou les volailles élevées dans les cours de ferme dont la viande avait du goût dû aux lipides, et dans le même temps, il souhaite une viande pauvre en matières grasses.

viande / porc / volaille / lipide / acide gras

1. INTRODUCTION

The consumption of meat products in industrialised countries has remained steady during the last years in Europe, but that of monogastric animals has increased: + 4% for poultry and + 5% for pork in 1998 [11]. Meat therefore remains an important basis of human nutrition. Pig and poultry are among the most consumed (Fig. 1).

Poultry has always been considered as a provider of generally consumed meat, whereas, for many centuries, the pig was first a supplier of fat for cooking in many Asian and European countries. This animal has been criticised for the abundance of its adipose tissues in relation to lean meat. In the pig, applied quantitative genetics has led, in Europe, to spectacular results in the decrease of backfat thickness and in the increase of muscle percentage [44]. At the same time, poultry growth has been improved, but, paradoxically, abdominal adipose tissue has increased [8]. A controlled feeding can however modulate this fat development. The task of the feeding specialist is therefore to define means to achieve a perfect restraint of carcass fattening and to increase output in lean meat, considering the impact of genetic, nutritional and economic factors.

The European consumer who eats 36 kg of pig meat and 24 kg of poultry meat per year [3] has a paradoxical requirement. If they are suspicious of the subcutaneous or abdominal fat storage, they will ask for meat with a minimal proportion of intramuscular fat, which is at the origin of flavour [13], regretting the fat of yesterday's pigs or the lack of fat in chicken skin after cooking.

Besides sources of proteins that they bring, meats and transformed products are also a source of lipids in human feeding. The utilisation of poultry and pork carcasses is different according to the species. Indeed, poultry is principally consumed as fresh meat, with or without being cut into pieces, whereas only 30% of pig carcasses are consumed as fresh meat. The remainder of the
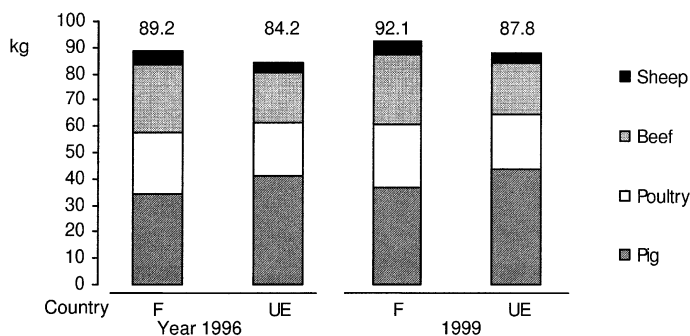

Figure 1. Evolution of meat consumption in France (F) and in European Units (UE). Comparison between species (kg per h and per year).

carcass is merchandised after direct transformation (ham) or after mincing and mixing in the preparation of different lean and fat tissues (sausage, pâté...). Thus, in these butcher products obtained after mincing, the added adipose tissues will have a considerable importance on the total lipid content. It is therefore important not to confound trimmed meat, where the visible fat has been separated, with transformed meat products.

After recalling the development and different localisations of adipose tissues, we will show the effect of breeding factors on the quantity and quality of lipids in the carcass, and their consequences on meat contribution in human lipid nutrition.

2. LOCALISATION AND ADIPOSE TISSUES DEVELOPMENT

2.1. Evolution of the body composition during the growth

Among meat production animals, pigs classically show high adiposity. For many years, the percentage of easily separable fat had reached 19 to 23% of the carcass weight for 105–110 kg of live weight, against 21 to 25% in bovines. At birth, however, lipid storage of the piglet is almost negligible since it represents 1 to 2% of the live weight which is a real problem for thermoregulation and the survival of the newborn [25]. The adipose tissue develops very quickly: it is increased by 10 after 12 days of age whereas at the same time, the live weight is multiplied by 3. The cellular development of pig adipose tissue is characterised by three successive phases: a dominant hyperplasy between 7 and 20 kg of live weight, a hyperplasy and a hypertrophy between 20 and 70 kg of live weight and a predominant hypertrophy beyond 70 kg [2].

During pig growth, the increase of fat storage is mainly a consequence of adipocyte filling. A positive relationship is observed between the cellularity of adipose tissue and the level of carcass adiposity. Therefore,

dietary factors will play an important role on the growth of adipocytes and on the importance of fat storage [17]. In the chicken, these three successive phases are also observed. The contribution of cell hypertrophy to adipose tissue development does not become significant before the age of 7 weeks, and remains important in the adult [40].

2.2. Lipid synthesis

In the pig, the privileged site of de novo lipid synthesis is the adipose tissue [17]. Eighty percent of lipids are synthesised from dietary glucose, which is the main physiological precursor of fatty acids [17]. In poultry, de novo lipogenesis is also performed from dietary carbohydrates. This lipogenesis, however, is essentially hepatic, which confers a primordial role to the system of triglyceride transport by lipoproteins, between the site of synthesis (liver) and the sites of deposition (adipose tissues) [18].

During the growth of the pig, lipid synthesis is chronologically occurs in subcutaneous adipose tissues, then in intermuscular adipose tissues and finally in intramuscular adipose tissue [26]. This depends on the age of the animal and not on its weight. Thus, more animals are slaughtered young, when less intramuscular adipose tissue is developed. This sometimes results in negative consequences for technological and sensorial meat qualities.

2.3. Localisation of adipose tissues

As for lipid synthesis, the adipose tissues do not develop uniformly. In the pig, they are usually classified into three categories depending on their anatomical position and their relative contribution to carcass adiposity [17, 20]. The subcutaneous fats constitute with the rind, the general envelope of the carcass and they represent 65% of the separable total fat tissues. Intermuscular fat, associated with connective tissues separating

median and deep muscular plans, represents 30% of the separable adipose tissues. Finally, the internal fat, mainly represented by the intestinal and perirenal fats, represents about 5% of total fat.

In the chicken at the age of slaughtering (6 weeks), the situation is the opposite. Subcutaneous adipose tissues are not easy to separate from the skin and they represent 18% of the body lipids. The separable adipose tissues represent 20% of the body lipids, and are essentially of visceral origin. The abdominal adipose tissue is the most represented (20 g·kg^{-1} of live weight), and it is eliminated during the evisceration process. The adipose tissues associated to muscles, and therefore to pieces of meat, are mostly in the thigh (8 g·kg^{-1} of meat), and are less abundant in the fillet (3 g·kg^{-1} of meat) [6].

2.4. Intramuscular fat

Compared to bovine meat, pig meat does not present a marbled aspect (except pigs from the Duroc breed). Intramuscular fat is not visible and not anatomically separable. The lipid content in muscles of the loin is about 1.5 to 2%. Once the visible fat is removed, pig meat is therefore lean, compared to bovine and ovine meats that contain 5 to 6% in lipids for the equivalent pieces. The lipid content is very variable according to the anatomical localisation of mus-

cles (Tab. I) but it is far lower than that in the adipose tissue (60 to 80% in a 100 kg pig). The situation is the same in poultry whose meat is especially lean, particularly if the skin is removed. In these species, there is an important difference between white meats (1% of lipids) and red meats (2%) [28].

However, confusion is frequently made, in the pig, between the global adiposity of the carcass and the real content in intramuscular total lipids. This confusion appears in tables of food composition and contributes to giving pig meat a negative image. It is paradoxical that pig meat is often advised against in diets whereas a slice of ham is accepted!

In muscles, lipids are contained in adipocytes. These adipocytes can be grouped along the fascicles of fibers or isolated between the muscular fibers. The proportion of isolated adipocytes varies between 10 and 20% of the total adipocytes [37]. The number and the size of adipocytes increase with the total lipid content of the muscle.

The proportion of neutral lipids and structure lipids also varies according to the muscles (Tab. II).

In the pig, the cholesterol content is lower than 25 mg per 100 g of *Longissimus dorsi* muscle and it is of 50 mg in the red muscles [12]. In the chicken, the values are between 20 and 60 mg per 100 g for white meat, and 20 to 70 mg for red meat [4, 21]. The

Table I. Lipid content (%) of some muscles of the pig or chicken at the commercial age of slaughtering.

Pig[1]		Pig	
Muscle	Lipid content (%)	*Semimembranosus*	1.7 ± 0.4
Longissimus dorsi	1.3 ± 0.3	*Semitendinosus*	3.5 ± 0.5
Adductor femoris	2.0 ± 0.5	Chicken[2]	
Biceps femoris	1.4 ± 0.4		
Psoas majeur	1.3 ± 0.3	Muscle	Lipid content (%)
Trapezius	2.0 ± 0.7	*Pectoralis*	1.0 ± 0.2
Masseter	1.8 ± 0.5	*Sartorius*	2.8 ± 0.3

[1] Large White.
[2] According to Rabot et al. [41].

Table II. Content in triglycerides and phospholipids (in g per 100 g of muscle) of different muscles.

Muscles	Pig[1]		Muscles	Chicken[2]	
	TG[3]	PL[4]		TG[3]	PL[4]
Longissimus dorsi	1.0	0.48	*Pectoralis*	0.5	0.48
Biceps femoris	0.8	0.63	*Sartorius*	2.0	0.83
Psoas major	0.7	0.72			
Trapezius	1.3	0.69			

[1] According to Leseigneur et al. [27].
[2] According to Rabot et al. [41].
[3] TG: triglycerides; [4] PL: phospholipids.

cholesterol content of these meats is therefore lower than for bovine meats (60 to 80 mg per 100 g of muscle). It can however be higher than 150 mg·100 g^{-1} in many butcher products, so it is important not to confound pig meat and butcher products.

3. INFLUENCE OF SELECTION OR BREED ON MEAT LIPIDS

In the pig, animal selection on the combined criteria of growth performance, feed conversion ratio and backfat thickness, has permitted to decrease backfat thickness to 9 mm and to increase the average daily gain to 150 g. Thus, the reduction of adipose tissue has been a benefit to carcass quality [22], but it also introduced problems into the transformation or the conservation of meat products, as well as possible changes in gustatory quality.

With the reduction of backfat thickness, an increase in the percentage of linoleic acid (C18:2 n-6) was also shown [29]. The increase in C18:2 n-6 (fatty acid originating exclusively from the diet) in the lean lines can be explained by the fact that the deposited lipids contain a lesser proportion of endogenous lipids than those in the fat lines. The dietary intake of C18:2 n-6 is identical in the two lines, however its proportion increases in the meat of lean lines. These modifications have negative repercussions on the adipose tissue during the transformation into meat products (decrease

in the melting point) but they are positive in terms of human diet quality (essential fatty acid supply).

In the chicken, selection against fattening is as efficient as in the pig and relies on direct (body composition) or indirect (metabolic parameters) criteria [24]. Practically, the reduction of adipose mass mainly concerns the visceral tissues, most represented in birds, that are eliminated during evisceration. It mostly benefits professionals because it increases the output of marketable carcasses, but far less the consumers because these adipose tissues are never consumed.

As for differentiated adipose tissues, the comparison of intramuscular lipid contents between breeds shows strong variations in relation to genotypes (Tab. III). These can have repercussions on meat quality. Indeed, intramuscular lipid content is related to flavour, as mentioned previously [13] and it could also influence the tenderness of meat [10]. The reduction of the total lipid content can induce a deterioration of these factors and therefore of sensorial meat qualities. So, it is important to control the effects of selection on intramuscular lipid content.

4. INFLUENCE OF BREEDING FACTORS

Feeding is one of the most important factors than can modify the quantity and quality

Table III. Comparison in intramuscular lipids of *Longissimus dorsi* of pure pig breeds or with a strong dominance of a major gene.

Breed	Lipid content	Breed	Lipid content
Large White	1.24	Tia Meslan	1.53
French Landrace	1.19	Gallia	1.51
Belgian Landrace	1.67	Penshire	1.66
Piétrain	1.35	Laconie	1.60
Duroc	2.41	Meishan	3.07

Expression in % of fresh weight, animals at the commercial age of slaughtering.

of meat lipids. The diet distribution (ad libitum or restricted) induces variations in adipose tissue weight but little variation in the lipid content of these tissues or muscles. By contrast, the nature of the diet is able to modify the composition of meat lipids.

4.1. Dietary lipids

4.1.1. Effect on lipid synthesis

With the same energy level, the increase of lipid content in pig feeding essentially leads to a reduction in lipid synthesis in the subcutaneous adipose tissue but with little effect on intramuscular adipose tissue [1]. In birds, hepatic lipid synthesis is inhibited. A balance is established between exogenous contribution and endogenous synthesis, and the total lipid content of the carcasses remains more or less constant [19, 43]. Whatever the species, this decrease in endogenous lipogenesis results from a reduction in dietary starch, replaced by lipids, which could induce a lack of substrate for fatty acid synthesis and from a direct inhibition of lipogenic enzymes by dietary lipids.

In pigs fed isolipidic diets, the activity of lipogenic enzymes changes according to the nature of the dietary lipids and their degree of saturation. It is higher with coprah oil than with tallow. But, in any case, it is the highest when corn oil is used in the diet [1, 36]. Similar regulations are likely in poultry, but available data are missing.

4.1.2. Effects on the fatty acid composition of tissues and consequences on meat quality

In pigs and chickens, the composition of fatty acid stores in adipose tissues largely reflects that of ingested lipids [16, 22, 33] (Tab. IV).

For intramuscular lipids (Tab. V), the fatty acid composition shows a less marked relation with the dietary lipids in the pig [23]. However, this relation is more pronounced if the diet includes a high percentage of unsaturated fatty acids, as observed with a high incorporation of linoleic acid [35].

In poultry, due to the small adipose tissue development associated to meat, the influence of dietary lipids is especially important on the muscular fatty acid composition. Thus, because of the relative abundance of phospholipids in muscles, meat can be efficiently enriched in polyunsaturated fatty acids in poultry [4, 42], as in pigs [38]. It is therefore possible to take advantage of the influence of dietary lipids on these deposits, in order to modify the nutritional qualities of the monogastric animal meat destined for human nutrition.

However, because the adipose tissue firmness is closely correlated to the melting point of fat [45], the increase in fatty acid unsaturation can cause technological difficulties in the processing of transformed products. A lack of adipose tissue firmness

Table IV. Effect of the origin of dietary fats on the composition in fatty acids of the subcutaneous adipose tissue in pigs and chickens (expressed as % of the identified fatty acids; only the main fatty acids are indicated).

Diet fats Authors	Pig			Chicken	
	Coprah Girard [16]	Corn oil Camoes [7]	Tallow Camoes [7]	Linseed oil Mossab [33]	Lard Mossab [33]
C12	1.1				
C14	11.1	1.1	1.3	0.4	1.5
C16	31.2	24.4	25.6	14.5	23.6
C16:1	5.8	1.5	2	2.2	4.9
C18	11.1	12.6	13.4	6.1	7.4
C18:1	28.2	39.3	44.3	27.2	43.3
C18:2	5.0	20.7	12.9	19.0	14.5
C18:3	0.3	0.4	0.3	30.4	3.3
Index Unsat[1]	1.19	1.34	1.23	2.01	1.31

[1] Index of unsaturation according to Girard et al. [16].

Table V. Effect of the origin of dietary fats on the fatty acid composition of the *Longissimus dorsi* (pig) and *pectoralis* (chicken) muscles (expressed as % of the identified fatty acids).

	Pig			Chicken			
	Tallow	Corn oil	Rapeseed oil	Tallow	Rapeseed oil	Linseed oil	Fish oil
C16:0	23.9	24.5	24.6	18.1	14.5	19.1	25.8
C18:0	11.9	11.7	11.6	12.5	8.6	12.4	7.7
C18:1	44.6	41.4	42.8	33.5	38.2	19.0	31.4
C18:2	11.1	13.8	11.8	18.4	21.4	23.8	14.2
C18:3	0.5	0.4	1.0	1.2	2.9	7.0	0.5
C20:4	0.1	0.2	0.2	8.0	5.5	3.4	2.3
C20:5	0.1	0.1	0.2	0.8	0.8	3.6	1.6
C22:5	0.1	0.1	0.1	2.0	2.1	4.7	1.0
C22:6	0.1	0.1	0.1	2.5	3.3	3.9	4.6
Index Unsat	1.27	1.33	1.29	2.03	1.96	2.53	1.99

According to Ratnayake et al. [42]; Ayudah et al. [4].

can provoke a blockage of grids during pressing. The conservation of butcher products is also more difficult when unsaturated fatty acids are present in too large amounts: oxidised products from linoleic acid appear, as well as an orange coloration of lard, that may cause rejection by consumers. Thus, to avoid problems during the transformation of pig meat, an adipose tissue with a good quality should not contain more than 12% linoleic acid and at least 12% stearic acid [16]. Adipose tissues containing more than 15% linoleic acid exhibit a loss of this fatty acid during conservation, equivalent to 10 to 20% of the accumulated quantity at the time of slaughtering. Products of linoleic acid oxidisation appear [7]. It is, however, possible to delay and/or to

decrease this oxidisation by supplementation with α-tocopheryl (vitamin E) in the feed, which is stocked in tissues and acts as an antioxidant [32].

In poultry, the enrichment of meat in polyunsaturated fatty acids is less of a problem than in pigs. On the one hand, most adipose tissues are eliminated in the slaughterhouse. On the other hand, there is little transformation of meat (butcher products). However, the peroxydation of polyunsaturated fatty acids can be a problem. Historically, it contributed strongly to the taste of fish oil [9] and it is still responsible for excessive dripping losses of unfrozen products [39]. In practice, 200 mg of vitamin E per kg feed are necessary for at least 4 weeks before slaughtering to optimise the vitamin content of muscles and to minimise lipid peroxydations [32, 39].

4.2. Effect of growth factors

The treatment of pigs with growth hormones has some beneficial effects on growth performances and feed efficiency [5]. Weight and lipid content of adipose tissues are decreased whereas the lipid content of muscles is little affected. This treatment also increases the proportion of unsaturated fatty acids in lean and fat tissues [34].

The treatment of chickens by β agonists, such as cimaterol, induces a significant increase in the muscle percentage in the carcass, a small increase in the intramuscular lipid content and an increase in meat tenderness [31]. Some similar effects have been pointed out in pigs after a treatment with ractopamin, that decreases adiposity and intramuscular lipid content and increases muscular mass [30, 46].

Thus, even though the effects of these growth factors can be considered to be beneficial for the quality of the carcass, there is a real problem concerning food security, not to mention the negative image of products resulting from treatment of the animals with hormonal factors.

4.3. Overfeeding and fatty liver

The fatty liver of overfed palmipedes is the expression of an exceptional hepatic steatosis since, in a fatty liver of good quality, lipids represent more than half of the weight, against less than 5% in control birds [19]. This steatosis essentially results from the accumulation of triglycerides (95% of lipids). These triglycerides are rich in monounsaturated fatty acids, with more than 50% oleic acid, and in saturated fatty acids (about 40%). By contrast, they only contain about 1% of polyunsaturated fatty acids, that are almost exclusively n-6 fatty acids [14, 15]. Finally, it is necessary to indicate that all lipids, and not only triglycerides, accumulate in the fatty liver, resulting in a dramatic cholesterol content that may exceed 1%. Thus, too rich in calories and in cholesterol, and poor in essential fatty acids, the fatty liver is a food very unbalanced from a nutritional point of view, however, the consequences for human health are negligible because its consumption remains limited.

5. CONCLUSION

For nearly 40 years, pig and poultry have had their growth performances and body composition greatly improved thanks to genetic selection programs and to a better knowledge of dietary needs. In the pig, the subcutaneous adipose masses have decreased, but in a near future and for all meats of monogastrics it will be necessary to ensure that this reduction does not affect intramuscular lipid content further since this is strongly linked to sensorial characters of meat.

Recent studies based on sensorial tests have shown that, in the pig, consumers would like a 3% lipid content in the *Longissimus dorsi* muscle [13]. It is necessary to work to increase the content in intramuscular lipids by 2 without increasing the global adiposity of the carcass, which would be

the opposite of all selection programs developed for more than 40 years. Similar studies are not available in poultry but we can expect that the desired values would be about the same, due to the impact of the lipid content on meat flavour.

Nowadays, the quality of products represents a real worry for the consumer, and it will be necessary to reconcile the wish of transformers, nutritionists and the economical context of pig production. Maybe the modification of the lipid diet will be able to improve the nutritional qualities of lipids in meat. It is therefore particularly important to consider the quality of added fats in animal feeding. It will certainly be interesting to study the evolution of polyunsaturated fatty acids in meat after cooking to determine what is really consumed.

In conclusion, monogastric animals produce lean meat when the visible fat is separated. Thus, for a better valorisation of the nutritional qualities of these meats, it is necessary to improve the information available to nutritionists and physicians and, in particular, it is primordial not to confound global adiposity of the carcass and real content in lipids of tissues, especially in the pig.

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